Public dialogue with science and development for teachers of STEM: linking public dialogue with pedagogic praxis

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Abstract

Despite evidence of quality teaching in Science, Technology, Engineering and Mathematics (STEM) subject domains (ACME 2007, Pollard et al. 2003) and insistence on the part of many national governments on the economic value of STEM, education, recruitment and retention into STEM subject fields and occupations is said to be continually blighted by a 'leaky pipeline'. In the UK context, schools are seen to benefit from a multitude of external STEM engagement and enrichment providers and STEM engagement initiatives, the contribution of which is to increase pupil interest, enthusiasm and awareness of STEM. However, despite evidence of the positive impacts of STEM engagement on learners, there exists a dearth of understanding related to how principles of STEM engagement can facilitate STEM teachers in becoming more pedagogically innovative and relevant and, therefore, engaging of their learners in the classroom context. Teachers are also at the nexus of tensions between STEM engagement and the pressures of the curriculum, the assessment system and other aspects of formal schooling. In this article, we employ a secondary data analysis of two prominent cases of public engagement in science and technology (PEST) in the UK to elicit combined lessons for STEM engagement and the pedagogical development of teachers. We consider the successes of science dialogue, which as one iteration of PEST, may be a fertile site for learning, in establishing principles of best practice that might be transposed to the development of teachers as more able and effective in the engagement of learners in STEM.

Keywords: STEM education; teacher development; public dialogues in science

Introduction

Public engagement with science and technology (PEST), the coalescing of non-expert communities and scientists in a process of mutual learning that reveals the cultural relevance of science and science as a cultural practice (AAAS 2016), is championed, most visibly in a policy discourse, for its ameliorative and interconnected effects of enhanced public understanding of, approval for, and trust in science and scientists (Holliman and Jensen 2009). It is also credited for increasing a public enthusiasm and interest in science (Stilgoe, Lock and Wilsdon 2014). PEST tends in most cases to be implemented on the basis of regulatory concerns of risk and trust (Bucchi 2004; Gauchat 2015) or as an effort to 'upstream' (Wilsdon and Willis 2004) public consensus in the generation of new legislative paradigms for science and technology. Critics, however, signpost the persistence of deficit-informed activities (Irwin 2006); of public engagement 'hitting the notes but missing the mark' (Wynne 2006) in the rehabilitation of public trust in science; and public engagement as a decoy for technocratic governance and publics' manipulation (Cooke and Kothari 2001) where it obfuscates the politics of science and its public participation (Chilvers 2008).

While, the focus of PEST is, habitually undifferentiated, *publics* (a taxonomy which encompasses both adults and children), its relationship with the formal schooling context is weak, tangential or non-existent. Moreover, PEST is not explicitly rationalised on educational terms, even if enhanced scientific literacy is an intrinsic aim. STEM engagement activities conversely, are deliberately targeted towards the engagement of learners, typically those in formal compulsory schooling, in science, technology, engineering and mathematics (STEM) subject disciplines. Furthermore, STEM engagement is distinctive for concentrating on the *early* less latter-stage acculturation of a scientific disposition and identification and nurturing of scientific talent. It is thus more about cultural affirmation than cultural remediation. Yet though PEST and STEM engagement may be driven by discrete foci, these are far from disparate. In fact it may be argued that the one is constitutive or at least facilitative of the other. In this case we suggest that STEM engagement of learners may be transformative and influential to their latter-stage role as scientific citizens, or even as scientists, better accustomed, prepared and motivated to meet the demands of PEST. Notwithstanding, a consensus on STEM engagement remains elusive and obscured by competing interpretations of what STEM constitutes in educational terms (Wong, Dillon & King 2016). For expediency, we adopt a generalist categorisation of STEM engagement as a smorgasbord of typically extra-curricular activities, events and experiences that are advocated and instigated (in similar terms to PEST) on the basis of locating and cultivating an interest in science among communities that are frequently external to and/or disenfranchised from its conversation.

STEM engagement activities are often seen as synonymous with informal and/or free choice educational spaces like museums and science centres (Falk and Dierking 2000; Schwan et al 2014; Stocklmayer, Rennie, & Gilbert, 2010) and contexts that are manifestly organised around an 'edutainment' logic like science shows (Watermeyer 2013) and science festivals (Jensen and Buckley 2014). They may also have a credential function administered through competition and award schemes (www.crestawards.org) or occur as policy initiatives that seek to kindle the imagination and aspiration of participants of formal schooling through the intervention of STEM role models; such as those provided by science ambassador programmes (Hermann et al. 2016). A political investment in STEM engagement, specifically, is rationalised in terms of its economic return and a near universal belief by policy-makers that a focus on scientific talent is beneficial to national economic competitiveness (OECD 2010; Royal Society 2010). STEM engagement is also rationalised on the basis of a social mission and as a means towards more equal and fairer participation within and access to formal education and employment opportunities, respectively (see Archer et al. 2012; Archer, DeWitt and Willis 2013; Archer, DeWitt and Osborne 2015).

STEM engagement much like PEST is typically organised as participatory activity that brings together scientists and non-experts or learners in conversation and practice. Frequently learners are provided with an opportunity to think and act like scientists. Their engagement is explicitly experiential and intentionally performative. Through various iterations of role-play, STEM engagement is intended to build self-confidence, self-efficacy and agency among learners; especially learners whose interactions and experience of STEM subject disciplines are more limited and/or marginal and constrained by what they lack in science capital (Archer et al. 2015). It is a type of boundary work (Akkerman and Bakker 2011) that facilitates the self-actualisation of learners and their teachers; the efficacy of their self-concept and their capacity to visualise and project future imaginaries in STEM where the borders that demarcate, separate and even antagonize their social and scientific worlds collapse (Watermeyer 2012, 2013).

STEM engagement may thus be experienced as a both a catalyst for social empowerment, social mobility and the future active citizenship of learners, and a means through which to identify and scaffold the development of the best scientific talent. While the two are not necessarily discrete functions, STEM engagement tends, despite its egalitarian overtures, to privilege the cultivation of the 'best' rather than most diverse learner constituencies. In fact, we would argue that despite multiple claims of STEM engagement as a conduit for widened participation, its audience is habitually narrow and selective and dominated by those already predisposed to STEM, often benefitting from an abundance of existing science capital, and recognised by their (nominating) schools as their most able and talented students and/or envoys (see also Dawson 2014).

The role of the teacher in addressing these challenges of engagement is crucial and in some cases STEM engagement has implied the bypassing of the teacher and engendered an emphasis on more direct engagement between scientist and learner. In the UK, the establishment of the Science Learning Centre network in 2004 brought teacher professional development back to the fore and provided a context for science teachers continued professional development (Bishop and Denleg 2006). Notwithstanding, STEM engagement with school-aged learners is a ubiquitous aspect of policy for the popularisation of science and it shares commonalities and crossover with other aspects of the PEST ecosystem such as citizen-juries and *café scientique* from which it may also learn. Moreover, we suggest that there is great value and potential in teachers learning from the technologies of elicitation (Lezaun and Soneryd 2007) operationalised in PEST contexts to remediate organisational deficiencies in STEM engagement and to help them in the early stage embedding of a scientific imagination and/or predilection among those they teach. Crucially we perceive the value in learning from PEST not only in relation to STEM engagement as the exclusive preserve of external, 'informal' education providers but as it might transfer to teachers in schools and influence their greater capacity for pedagogical innovation and ability to engineer and sustain an inclusive and egalitarian classroom environment. This is not to suggest that many teachers are not already pedagogically expert, innovative and successful in the engagement of learners in STEM. Instead the question here is on how these competencies might be further supported and enhanced through the cross-fertilisation of ideas and more of a whole-community approach to teacher development in STEM.

As we have already noted, increasing engagement with STEM has become a priority in many countries and in both the United States and the UK there is a proliferation of initiatives designed to improve learners' engagement with science both within and beyond the classroom (Gamse, Martinez and Bozzi 2017). Despite the establishment of the Science Learning Centre networks, teacher development and teacher education for STEM education has received much less attention, and policy guidance for teacher education in the UK remains fragmented; although there are examples of exceptionally good practice (including where subject societies offer teaching programmes). In addition to this, whilst teacher education programmes in the UK and internationally habitually have some focus on subject specific pedagogy, this tends to be centred on approaches to assessment, pedagogic discourse and scientific enquiry and the use of ICT rather than on developing teachers' engagement with knowledge of science and judgments on complex scientific issues (Teo and Ke 2014). The erosion of emphasis on subject specific pedagogy is characteristic of changes to teacher education policy in the UK over the last 25 years. With more emphasis on 'school-based' approaches and a broadening of routes into teaching, subject specific pedagogy has been marginalised. Despite recent initiatives in STEM specific schools such as University Technical Colleges (UTCs) in the UK and also in the United States where there are now in excess of 100 specialist STEM schools across 30 states (ibid.), the training for specialist teachers of STEM remains fragmented.

In this article, we consider how a concern for engaging learners in STEM classrooms, where issues of subject disinterest, disenchantment and attrition continue to prevail (IET 2008), may be mediated by the co-option of alternative methodologies and architectures of PEST. Specifically, this paper focuses on one of the preeminent models of PEST, the public dialogue (Einsiedel 2008), and how public dialogues (or science dialogues) in emergent and controversial science and technology, provide structures for developing teachers' knowledge, pedagogic innovation and engagement in STEM disciplinary contexts. We elucidate principles for success in the science dialogue and propose that these might be transposed to the context of pedagogical development and innovation. Concurrently, we use these principles of best practice in PEST in order to identify opportunities for an approach to STEM engagement that is not restricted to external provision but re-centred on everyday classroom practice. We contend, therefore, that teachers can be significant actors within a PEST ecosystem as much as scientists and professional science communicators are, and they can become what Rose (1999) calls experts of community and thus positive contributors to the enhancement of teaching in STEM. The potential of the dialogical approach enacted in PEST is then, where transposed to the classroom, that which enables teachers to transcend the organisational prescriptiveness and primacy of their role as deliverers of the curriculum to co-conspirators of the scientific imagination.

Methodology

This article offers a secondary analysis of two existing research projects on public dialogue in science and technology and these are outlined in more detail below. Reviewing secondary data sources is an approach which is becoming more prevalent, partly as a result of the increase in open access to data sets. Secondary data analysis is consequently being seen as its own form of empiricism, involving a systematic approach with rigorous evaluative steps (Johnstone 2014). The rapid increase in researchers (particularly in the social sciences and professional disciplines) engaging in time-consuming primary qualitative studies and the availability of this data has engendered efforts to capitalise on (and draw meaning from) this rich existing data set (Howell-Major and Savin Baden 2011). The increased pressure to demonstrate impact in research has also resulted in a need to bring research "closer to the practitioners who can use it to improve practice" (ibid., 646) and this has led to the further development of secondary data analysis approaches where information from a range of sources is re-analysed for particular aims and purposes. Secondary data analysis or the integration of qualitative (and also quantitative) evidence is distinctive from traditional research review as it entails the extraction of data from existing published sources and the development of a new analysis (Howell-Major and Savin Baden, 2011). There are a number of methodological approaches to this, but in the case of this study a qualitative meta-analysis was used, where primary qualitative data was synthesised into a theoretical model and principles drawn out (ibid.).

The evaluation reports of the two selected projects were re-analysed to generate critical reflections and implications for teacher development. From this analysis principles were drawn out in order to construct an architecture of dialogue between public engagement with science and technology and teacher development. This paper provides a discussion of critical reflections upon the two public dialogues that combine the first author's direct experience as a dialogue evaluator and his written reports with the input of the second author as an expert in teacher development. This discussion thus triangulates empirical observation of the dialogue phenomenon from an engagement/evaluative perspective with the secondary analysis undertaken through a pedagogical lens, to determine the transferability of an engagement method and its impact(s) in the development of teachers' pedagogical competencies. Crucially, our findings are thus themselves the product of a dual perspective dialogue.

The paper considers directly two cases of public dialogue in science (set within a wider context of a science and society UK government initiative), sponsored by Sciencewise which between 2012 and 2016 was the UK's national centre for public dialogue organised for the explicit purpose of producing better policy in science and technology issues. Whilst both of these dialogues were set in the UK context, this paper aims to draw out principles which could be applied in other international contexts where there is a perceived need for intensified focus on specialised training for STEM teachers (such as Singapore: Teo and Ke 2017). These dialogues explored: 1) patient and public views on the research approval process in health research contexts; 2) public views on new regulation/legislation for mitochondrial replacement technology. Both dialogues involved workshops that were run by professional facilitators and attended by a randomly generated sample of public participants across a range of UK cities. The dialogue workshops also involved scientific specialists and the independent evaluator (Watermeyer and Bartlett 2013; Watermeyer and Rowe 2013). Each workshop featured a broad cross-section of public participants with various social profiles (age, gender, ethnicity). In both cases, the dialogue workshops resulted in tangible operational advice. The first dialogue focused on research approval processes which resulted in the modification of organisational and management protocols. The second dialogue focused on mitochondrial replacement technology and resulted in new regulatory powers and licensing for research in assisted reproductive technology. The evaluation reports of both dialogues, however, also reveal a major contribution to the mutual learning of public and scientific constituencies, an outcome reported in numerous other science dialogue evaluation reports (Watermeyer and Rowe 2013, 2014; Rowe and Watermeyer 2016).

The science dialogue

The science dialogue of our experience and discussion is a deliberative event, where non-expert members of the general public are recruited into what is typically a day-long workshop where they are introduced to and asked to discuss a scientific topic of some ethical, social and usually scientific complexity. The deliberative dialogue approach is most frequently used as method for eliciting stakeholder values and opinions (van de Kerkhof 2006) and knowledge translation and exchange (Lavis et al. 2009) that informs policy development (Cuyler and Lomas 2006). The two dialogues of our discussion featured aspects of citizen jury (Crosby 1995) and consensus conference (Joss and Durant 1995) methodologies. Concurrently they operated as a kind of extended peer-review (Funtowicz and Ravetz 1994) and technology assessment (Rip et al. 1995). As deliberative events, dialogue participants were asked to focus and critically reflect upon their own attitudes, perspectives and (no matter how remote or tangential) experiences as related to the science and/or technology and problematise these through collective discussion and consideration of a range of stimulus materials. Discussion was facilitated by a moderator who provided contextual information and posed questions and problems for the dialogue group to resolve. Each dialogue consisted of up to and around twenty participants whose involvement should be noted as voluntary although financially incentivised with a modest payment. They were organised into smaller sub-groups of five or six that worked to specific questions and subsequently fed back at intervals to the entire group.

In the UK, an explicit dimension within the rationale for public dialogue is a contribution to learning. Moreover its impact has been recognised in the terms of influence on "the knowledge, attitudes and capacity… to be involved in public dialogue" and in stimulating "collaboration, networking, broader participation and co-operation in relation to public engagement in science and technology" (Sciencewise 2013, 6). Public dialogue, therefore, is a means of relativising scientific innovation as a public concern and a means of generating a closer interface (through conversation) across public, policy and scientific communities, primarily through the mobilisation of the (inexpert) public as a credible and cogent voice in the discourse of science governance (Wilsdon and Willis 2004). From the perspective of the general public *qua* scientific novice, it is perhaps a unique opportunity from which to exercise democratic citizenship and a means with which to connect social and scientific worlds while evolving a deeper understanding of science and the complexities of its governance. The contribution of public dialogue to the architecture of formal science learning is therefore profound, where the ultimate goal of science education (in a democratic, science and technology economy) is the same ambition of enhanced scientific literacy. Furthermore the complementarity or homogeneity of such goals (PEST and formal education in science) are confirmed by a shared aspiration of equal, inclusive and diverse participation.

Participants across science dialogues uniformly speak of having learnt "a lot of new things", particularly in relation to the science or technology under discussion. A majority of participants also speak of having had their views changed, though the majority of these same persons also speak of having little prior knowledge of the subject area. Evaluation findings, certainly those emerging from exit-poll questionnaires, explain the success of dialogues in the terms of participation and specifically of having had "an opportunity to speak and to be heard"; and "an opportunity to be involved in collective discussion". Participants directly speak of their involvement in the respective dialogue as a "learning experience" and significantly, as that which has made them "more likely to get involved in [dialogue] events in the future" (Watermeyer and Rowe 2013).

As a site of (informal and though desired, perhaps incidental) learning, the dialogue workshop is explicitly interactional and participatory and mimics the conditions of experiential models of learning (Kolb 1984). It is also explicitly deliberative, with public participants co-opted as independent judges asked to mediate the ethical and social complexity of scientific innovation through a negotiation of different scenarios and response pathways in an attempt to find collective resolutions and consensus and concordantly better options for policy formation. In such a way the public dialogue strongly resonates with forms of student-centred and problem-based models of teaching and learning, which may of course be perceived as both a good and bad thing by teachers. For instance, whilst enabling a more immersive learning experience, these pedagogical approaches may be criticised and avoided by teachers for lacking the kinds of transmissional efficiency, perceived to be preconditional to their satisfying the outcome-oriented and results-driven expectations of what is in the UK, an aggressively neoliberal model of compulsory education.

The role of the dialogue facilitator and classroom teacher are also in parts analogous, with many constructivist models of teaching and learning situating the teacher as not an instructor but facilitator. In such context the manner with which dialogue facilitators mobilise public participants, non-expert in scientific matters and concerns, as competent and confident discussants of science policy, is in ways akin to the teacher stimulating the self-concept and self-actualisation of the classroom learner in STEM. Yet, again we would caution, that the science dialogue and science classroom, as respectively implicit and explicit learning ecosystems, are rationalised on aims that are not necessarily or always congruent. Specifically, new learning is distinguished between the respective contexts for being a desired or essential outcome.

What makes successful dialogue?

Dialogic education emphasises the significance of communicative interactions in learning and privileges the interaction of student voices with the voices of teachers and the curriculum. These dialogic practices allow for elaboration of knowledge in the context of equal social participation (Fernandez-Cardenas 2014) and are seen as particularly crucial in science learning where it is important to consider conversations between paradigms regarding problems and their solutions (ibid.). Despite the espoused importance of dialogic learning, some educationists have voiced concern over the space available for dialogue in the curriculum and the "authority of scientific knowledge in educational practices" (Fernandez-Cardenas 2014, 3). Here we look to the public dialogue to try to ascertain how this may inform dialogic practices for teachers in schools. There are many social, contextual and educational boundaries to be crossed in this translation of dialogue from the public sphere to the school context but we see teachers, their learning and their engagement with public dialogue as a potential means to translate principles of dialogue from the public to the school setting.

If we are to deduce what accounts for the success of the public dialogue and thus translate it for teachers, we must look towards its social architecture and the manner with which it orchestrates a form of social participation that is explicitly inclusive and welcoming of diversity and which embraces a polyphony of voices (Bakhtin 1984). The aim of this dialogue is to stimulate meaningful conversation within a heterogeneous if not potentially disparate public congregation, whose members hold different if not antagonistic and/or polarised views on a subject, their knowledge of which may be superficial. The starting point of the public dialogue is not then so massively different from the typical baseline of nil that characterises most learners' initial forays in formal science learning. The major difference being, life experience and the greater accumulation of this by public dialogue participants; though this can vary with the public dialogue tending to feature a broad age demographic.

In our evaluations of public dialogue, we have applied the meta-criterion of information translation, which provides the most comprehensive means with which to test the quality and efficacy of the dialogue process (Horlick-Jones, Rowe and Walls 2007). The translation criterion focuses on the efficiency of information and knowledge transmission and interpretation: comprehensiveness and appropriateness. We have used it to extend and build upon on what Sciencewise (2013) has produced as guidance to high quality dialogue. This guidance stipulates that public dialogue requires clarity, from the outset, in the formalisation of its purpose and objective; that the dialogue occur 'within a culture of openness, transparency and participation'; that it is sufficiently resourced in terms of 'time, skills and funding'; that it adopts a broad approach to question-making/framing that stimulates more holistic discussion; that there is honesty concerning the extent of outcomes and how public input generated through the dialogue will be used (i.e. informing *not* developing policy). Moreover, Sciencewise (2013) advises that dialogue ought to be respectful, equal, nonconfrontational, without bias, and accommodating of a plurality of views. This concept of plurality is strong in Bakhtinian dialogue where “all distance between people is suspended” and there is “free and familiar contact among people” (Bakhtin 1984, 123; Fernandez-Cardenas 2014).

Adding these aims to the ‘translation’ criterion, we have sought through our evaluations of public dialogue to determine the extent to which public participants have found the information provided within the respective dialogue to be clear; that they had a clear understanding of why they had been invited to join the dialogue, its aims and the larger process it was a part of, in other words, the *context* of the dialogue and their involvement. Again this has echoes of Bakhtin’s construction of dialogue where positioning is key to the construction of successful dialogue and participants’ positions (less fixed than roles) change through the processes of social interaction (Bakhtin 1984; Fernandez-Cardenas 2014). Furthermore, in assessing the ‘translational efficiency’ of the dialogue *process*, we have evaluated (through observation, stakeholder interviews, and exit-poll analysis) the extent to which public participants believe they have been provided an opportunity for full disclosure and that they have said all that they wanted to say; that they have been provided adequate time to discuss all that needed to be covered; and that any summing-up and feedback was accurate and true to their perceptions or accounts of what was discussed.

In one of the best examples we have observed, from the perspective of conducting independent evaluation, the public dialogue on mitochondrial replacement technology (Dialogue 1), a highly ethically contentious and contested area of scientific innovation, highlighted not only what makes for good dialogue but the kinds of transformative learning that can emerge through skilled stewardship (Watermeyer and Rowe 2013, 7-8). These evaluation findings, though our own, point to how a public dialogue process instigates learning from multiple perspectives involving multiple actors, again in the spirit of Bakhtinian plurality, and yet in such ways as illuminates, for non-expert public participants in particular, the ubiquity of science in their day lives. Thus through the example of multi-stakeholder dialogue, comes an opportunity for the teacher to visualise the potential of transforming and scaffolding learners imaginaries in science and the cultivation of learners' self-concept and agency where scientific-exoticism is made visible and accessible within the mundaneness of everyday life (Watermeyer 2013):

> The dialogue has also served as an exercise in active citizenship, with all participants across the workshops, relishing the opportunity to be involved and included in such debate; and as a process of experiential learning with all those involved discovering much about science and technology; policy-making processes; about the views of the public (and thereby the diversity and plurality of views held by other participants); and ways with which science and technology are ubiquitous components of public citizens' everyday lives. (Watermeyer and Rowe 2013: 7)

The success in enabling public participants' dialogical interactions with science is also based, as seen from Dialogue 1, on facilitators establishing a safe space for knowledge interactions. Indeed, in this example, the dialogue participants' enjoyment of the dialogue space and a sense of goodwill among participants is credited for the success of knowledge exchange and the confidence and sense of self-efficacy among public participants as 'licensed' contributors to scientific discourse:

> Participants were well-scaffolded throughout the dialogue process; were provided a safe and secure environment with which to openly share their ideas and opinions without fear of appearing foolish, ignorant or open to the reprisal of others. Indeed the dialogue process throughout was characterised by good-

> will among participants and general sense of bonhomie. The role of the facilitators was integral to this, in generating and maintaining a relaxed, trusting, respectful, good natured and good humoured, and enjoyable dialogue experience among all participants . . . . in most instances participants reflected that their workshop experience had been highly enjoyable and fulfilling and had bolstered their appreciation not only of science and technology developments (R&D) and science policy issues, but their own everyday interface with these.
> (ibid.)

There are further Bakhtinian echoes here where ‘carnival’ is a crucial part of dialogue and “there is a weakening of… one-sided rhetorical seriousness” and dogmatism and solemnity are diluted (Bakhtin 1984, 107; Fernanzdez-Cardenas 2014). The parallels here to the creation of an optimum learning environment are evident and reinforce a need, particularly in the context of formal science education which the research literature tells us is blighted by what can be fierce (habitually gendered) competitiveness among learners, for creating ‘collegial’ spaces in the cultivation of ‘science capital’ (Archer et al. 2015). In a similar vein, the success of public dialogue in science, though seemingly self-evident, may be attributed to creating an opportunity for individuals both to hear and be heard and more especially in the context of discussing subject knowledge they may know little of or be disenfranchised from (though it permeates their everyday lives). As such, the contribution of the public dialogue in invoking the agency of the public participant as scientific citizen, is that of the teacher culturing the confidence and capacity of the learner to engage in subject knowledge that may seem out-of-reach:

> Participants in this context clearly relished an opportunity to listen and be heard and to have their say on matters they would ordinarily perceive as out-of-their-grasp yet as the workshops revealed were, in most instances, an integral component of their everyday lives.
> (Watermeyer and Rowe 2013: 8)

Our final observation of what constitutes good dialogue from this particular case study, is that related to quality moderation and the role of the facilitator in guaranteeing equal opportunity among public participants to hear and be heard:

> The facilitators' multi-faceted role as custodians of fair, inclusive and equitable exchange; as catalysts of dynamic and creative dialogue and in part choreographers of process was in our estimation very well balanced. Facilitators were supportive without suffocating; provided leadership without leading; and appeared true in their interpretation of participants' contributions. Furthermore, we observed genuine skill among the facilitation team when working with difficult and domineering participants. They demonstrated in these instances an ability to cauterize the potential of participants' sabotaging or derailing the dialogue process, yet in such ways which still managed to engage and not segregate more boisterous or troublesome individuals".
> (ibid.)

In this account, we draw parallels with the role of the teacher in having to monitor, regulate and often police the various 'contributions' of classroom learners and the skill that is required in ensuring parity among learners in their classroom interactions. Here Bakhtin's construct of sequentiality is relevant where speakers begin to appreciate the significance of what precedes his or her intervention and each turn anticipates the future contribution of other interlocutors (Bakhtin 1986; Fernandez-Cardenas 2014). We contrast this with the skill demanded of the teacher (facilitator) in balancing a need to protect the welfare of classroom (dialogue) participants whilst also challenging them to develop further in their thoughts and ideas. This is also consistent with Bakhtinian (1984) constructions of polyphony in dialogism where many voices are prioritised over the voice of the teacher. Bakhtin talks about the presence of different voices which together form a worldwide dialogue.

When we delve deeper into the choreography of public dialogue we begin to ascertain a range of other features that might well correspond to the making of superior pedagogical competencies among teachers. We reflect here on both dialogues but particularly the public dialogue on patient and public views of the research approval process (Dialogue 2) as one that produced a significant amount of formative learning in relation to dialogue processes; what is necessary and what is necessary to avoid.

Establishing principles for successful dialogue

The Dialogue 2 evaluation report signposted what we might think of as five core principles to dialogue design and implementation that are applicable to the teaching and learning context. In fact, we would argue that these five principles are as salient to the success of the dialogue facilitator in as much the classroom teacher. The principles focus on the ideal behaviour of facilitators in the dialogue context and their handling of dialogue resources. These principles we suggest are concurrently applicable to the ideal behaviour of teachers in the classroom context and their handling of pedagogical resources.

Principle 1: (Clarity of roles and expectations) calls for an explicit demarcation of dialogue roles, specifically the 'conversational' and 'informational' roles of the facilitator and scientific expert (where present), respectively. Such demarcation will frame the expectations and etiquette of public participants; whom they call upon to help them navigate the ‘conversational’ and ‘informational aspects’ of the dialogue, and what they might reasonably expect from such parties.

Principle 2: (Balance and impartiality) is related to Principle 1 and demands that dialogue facilitators and collaborating (scientific) experts insulate the dialogue process from all personal views, beliefs and attitudes towards the dialogue topic and exercise restraint in their contribution to the dialogue, recognizing their contribution is *facilitative* and not *generative*. Principle 2 also demands that time be built into the dialogue for verification of dialogue findings and that dialogue participants are allowed to sense-check feedback provided by the dialogue facilitator(s).

Principle 3: (Expansive yet on-point moderation) calls for skilful moderation on the part of the dialogue facilitator and an ability to steer discussion in a way that is exploratory and expansive yet without becoming digressive or meandering.

Principle 4: (Incremental sequencing) calls for appropriate sequencing of the ‘informational’ and ‘conversational’ aspects of the dialogue. The dialogue must not necessarily follow a linear design but should adopt an incremental approach to knowledge transmission, assimilation and synthesis; where public participants are provided sufficient content knowledge to sanction their deliberative discussion.

Principle 5: (Appropriate selection and use of stimulus materials and lines of questioning) demands that the dialogue process is supported with appropriate and relevant stimulus materials, chosen with the input of content experts. Concurrently, leading-lines of questioning (that might reflect and reproduce bias) and content-specific or laden questions that might cause to confuse and/or exclude public participants should be avoided.

Transposing principles for successful dialogue to principles for successful teaching

In the context of each of these principles, it is possible to draw parallels with how science teachers, and teachers of any subject discipline for that matter, might approach the task of deepening the engagement of their learners in STEM subject knowledge through dialogue. The principles also, however, where transposed relate to how multi-faceted the teachers' role is and the difficulty of embedding a strategy for successful dialogue into teaching practice. For instance, in principles 1 and 2, where it is argued that the role of the facilitator should be kept distinct from the scientific expert, the teacher's classroom responsibility is conversely both facilitative and generative, conversational and informational. An expectation of the teacher as polymath produces limitations of the kind reflected in dialogue processes, where facilitators may be mistaken for having in-depth subject knowledge when they do not.

In reality, though teachers may have subject expertise, this may be restricted to curriculum content, meaning that the contribution in terms of scientific expertise that exists beyond the school and for instance in universities that supports learner engagement and progression, becomes all the more valuable and important, to a wider, more nuanced and sophisticated understanding of science. Principles 1 and 2 are also significant for what they intimate when transferred to a school context, about reasonable expectations made of teachers and how teachers' pedagogical contributions might be enhanced through external intervention and/or partnering and this in turn broadening not only learners' but teachers' perspectives on content knowledge and mitigating the threat of one-dimensional and/or biased knowledge interpretations and transmissions. Watermeyer and Yeoman (forthcoming) for instance report on how the involvement of university scientists in the school setting provides a valuable interstice to teachers' everyday teaching practice and an opportunity to pause and view their learners and their learning competencies/aptitudes through a different lens, helping them to critically reflect upon, modify and ultimately improve their pedagogical outlook and interactions. This form of dialogue is known to teacher education as it is modelled in the partnerships between university education departments and schools. Teacher educators from a university are often perceived as sources of theoretical knowledge that will support teachers in their practice. This process is recognised as 'professional dialogue' in the teacher development literature (Cheng and So 2012) and is perceived to have a "positive impact on teachers' knowledge and competence in applying new pedagogies" (ibid., 326).

In the same way, in the public dialogue scientists are provided with fresh perspectives that public participants provide. Take for instance, the following two scientific perspectives on the dialogue process and the gain attributed to the public perspective, further confirmed in another recent evaluation of a dialogue focused on the research priorities of an agricultural research institute (cf. Rowe and Watermeyer 2015)

> 'What the public said really had merit and was coming at the issues from a different space. I think that if you're less accustomed in these things, you're

likely to approach them in a different way and without the baggage of past experience.'

'It was really interesting to see the participants in the public groups approach and tackle these issues for the first time. I think this whole process provided a fresh pair of eyes.'

(Watermeyer and Rowe 2013)

These accounts also articulate a sense of dialogue processes as clearing-spaces that help to mitigate prejudicial or misinformed understandings of science that might be similarly repeated as opportunities in the classroom context for the teacher to recalibrate learners' perspectives, associations and engagement with science. Teachers' own misunderstandings about science are also seen as a barrier to effective engagement with STEM teaching (Watermeyer, Morton and Collins 2016) and this particular form of dialogue could address areas of teacher misinformation.

With regards to principle 3, it is important to underline that dialogues in science should be both open and expansive yet also disciplined enough so that they do not veer too far from their core focus or become distracted or subsumed by other concerns or interests. In the parallel world of the classroom, the teacher is challenged to both stimulate the imaginative and creative capacities of learners, potentially through participatory and dialogical interaction, and cultivate learners' autonomy and agency, yet without abandoning a focus on the development of subject knowledge and cognate skills. The core message from principle 3 then relates to breadth of knowledge without forgoing depth. The parameters or terms of knowledge acquisition (for dialogical fluency) are re-emphasised in principle 4, which again transposed to the classroom, makes clear how foundational knowledge is prerequisite to the acquisition of learner agency and the mobility and agility of learners in navigating subject knowledge. This principle for successful dialogue chimes loudly with that of successful teaching and learning, which asserts the primacy of time and patience and the incremental development of the learner. Finally, in principle 5, we observe the significance attached to the material contours of dialogue and thus early instruction/knowledge transmission, where the selection of resources designed to ignite and sustain the interest of dialogue participants (learners) is given special focus (see Hetherington and Wegerif, this volume). In this context, we see parallels with museum pedagogy and a partnership between museum 'educators' and classroom teachers in the design, development and implementation of learning materials (cf. Watermeyer 2015)

Discussion

The discipline of teacher education suffers from low status and marginality as a generator of expert knowledge as it has often been compared with longer established or 'traditional' disciplines and seen to be inferior in terms of its knowledge base of professional knowledge and pedagogy (Murray 2012, 598). In this sense, engagement in public science dialogues could raise the status of teachers' knowledge and an engagement with principles of public dialogue as outlined above could provide access to and ways of using that knowledge for teachers and their learners.

Crucially, the science dialogue evidences the plausibility of scaffolding non-expert publics' rapid acquisition and mediation of scientific knowledge, which frequently concerns developments that are controversial and ethically complex and liable to provoke emotive and polarised discussion. Thus we see a significant burden of responsibility placed upon the facilitator. We find also from interrogation of the evaluation accounts, honesty and realism in relation to the conditions and values that serve as enablers for the efficacy of this process, which we argue are transposable to the pedagogical context and to guiding the response of teachers to similar challenges.

What we have established as a set of principles for best practice in science dialogue is in terms of the development of teachers of STEM, transferable, salient and potentially influential to how they might produce and curate conditions for deeper, more immersive, expansive and sophisticated forms of learner engagement and negotiation of (scientifically, socially and ethically) complex knowledge. Moreover these principles, where transposed to the classroom context, provide a values-guide to achieving democratic (and deliberative) participatory learning that: i) is realistic to and accommodating of potential shortfalls in teachers' subject expertise; ii) is sympathetic to the restrictions of time and other organisational, cognitive and behavioural determinants such as bias that might undermine or enfeeble the potential of the teacher to affect transformative learning; iii) centralises the role of the teacher in relativising science and the value of co-opting non-scientific discourses, though risk-laden, in the elucidation of science; and iv) prioritises through the creation of a safe, inclusive and respectful space, the agency and autonomy of the learner as creative, critical and reflexive thinker. This assertion of values is, we contend, the contribution of the science dialogue to teacher education, in as much as it facilitates delineation of the challenges, needs and potential response protocols for teachers in engaging learners in STEM.

From a process-based perspective, the most successful public dialogues are those that adopt a multi-actor approach and utilise and coalesce expert dialogue facilitators (science communicators or more often than not in the UK, market or quasi social research consultancies); dialogue sponsors (a policy or practitioner community); and scientific experts (those with recognised authority and substantive understanding of the scientific dimensions of the topic being deliberated). However if the quality of public dialogue and by extension publics' scientific literacy depends on the involvement of more than one type of facilitator, what are the implications in transitioning such practice into the classroom and for the development of teacher competencies? We are aware of the challenges presented by the different social, cultural and educational contexts of the public and school spheres. We would argue that teachers require a partnership approach to the development and delivery of curriculum that involves other educational stakeholders be they from the informal educational sector; from universities; or from industry, but that this approach exists largely beyond the current framework for teacher training, which tends to emphasise the competencies of the teacher, typically as a lone-worker.

As one example, Watermeyer (2015) in a study of a museum pedagogy approach to science teaching, reveals both the benefits of teachers working in tandem with museum curators and community outreach workers and an appeal from newly qualified teachers that such an approach forms an integral yet currently absent part of teacher training. Numerous other studies we have been involved in point to the importance of teachers being supported and indeed, having their pedagogical repertoires enriched through exposure to and collaboration with other STEM stakeholders and in the context of STEM careers guidance; schools-university partnership; and STEM Ambassador schemes. Evaluation studies of these kinds of initiatives tend to focus on the impacts on learners' enthusiasm and interest in science and rather less forcefully elucidate and advocate for the ameliorative effects on teachers. This is an oversight. The long-term impact of any engagement and enrichment intervention depends upon the successful translation, embedding and retention of good practice and what works, which rests fundamentally with the enhanced capacity of teachers to engage their learners.

There are initiatives in both the UK and the United States that aim to promote an integrated approach to the teaching of STEM content areas which enables a shift towards emphasis on 'doing' STEM through authentic inquiry as opposed to simply learning content in discrete disciplinary areas (Sinatra et al. 2017). Research also suggests that an interdisciplinary or integrated curriculum generates "more relevant, less fragmented, and more stimulating experiences for learners" (Furner & Kumar 2007, 186). Whilst this approach often centres on a particular STEM issue or problem (e.g. Speedometry in Sinatra et al, 2017) it offers a more holistic approach in the same way that public dialogues engender holistic learning from emerging problems of science in society. This integrated (and public dialogic) approach sharpens the question of what skills, beliefs, knowledge bases and experience teachers would need to guide this form of teaching and how training can prepare teachers for this more dialogic form of teaching (Stohlman et al. 2012).

Given that initial teacher education programmes internationally have increasingly taken a ‘practicum turn’ (McLean Davis et al. 2015) where in-school experience is perceived to have an ‘optimal value’ in learning to teach (ibid., 514), other forms and sources of knowledge in addition to the traditional teacher education department in the university are being sought. Consequently, the contribution of public dialogue to the development of teacher competencies lies with a recognition that the teacher cannot go it alone and that the success of classroom practice is indelibly linked to a whole-community approach, certainly in the milieu of science.

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